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Understanding welding practices on shipyards

An ethnographic study for designing an interactive robot welder

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Abstract —The aim of this ethnographic study was to understand welding practices in shipyard environments with the purpose of designing an interactive welding robot that can help workers with their daily job. The robot is meant to be deployed for automatic welding on jack-up rig structures. The design of the robot turns out to be a challenging task due to several problematic working conditions on the shipyard, such as dust, irregular floor, high temperature, wind variations, elevated working platforms, narrow spaces, and circular welding paths requiring a robotic arm with more than 6 degrees of freedom. Additionally, the environment is very noisy and the workers – mostly foreigners – have a very basic level of English. These two issues need to be taken into account when designing the interactive user interface for the robot. Ideally, the communication flow between the two parties involved should be as frictionless as possible. The paper presents the results of our field observations and welders' interviews, as well as our robot design recommendation for the next project stage.

Keywords-component: *ethnographic study, interaction design, user observations, user interface, industrial robots, welding practices, shipyard environment*

I. INTRODUCTION

The use of robots in industrial environments promises an efficient and automated approach to obtain high quality work in a short time, reducing operational costs and limiting the exposure of the workers to hazardous environments.

In modern assembly factories there is a wide range of industrial robots deployed for different tasks. Concerning welding robots one of their most common application areas is the high production industry, such as the automotive and electronics industries. Given the importance of welding robots in the industry there is a large number of research projects focusing on advanced algorithms for automatic robot control in hazardous or challenging environments [1][2][13][4].

Due to the difficulty and costs of implementing a highly flexible robot in most cases the welding robot is stationary and the work pieces approach the robot. In our current project one of the main goals is to develop a robotic welding solution in motion. In this scenario the robot approaches the welding piece and performs the welding tasks autonomously at both horizontal and elevated locations (i.e. jack-up rigs). Additionally, the robot will be equipped with a multimodal user interface that will enable welders to communicate and program the robot easily.

To be able to inform the design of novel robots and consider the contextual aspects of the shipyard settings, we carried out a small-scale ethnographic study. In this paper we present the results of our study performed at one of the largest shipyards¹ in Singapore, as well as the implication for the robot design. The paper is organized as follows. Section 2 presents information related to welding processes on the shipyard-although a detailed explanation of welding processes is beyond the scope of this paper, it is important to understand the terminology used along the paper, as well as to get a brief overview of the different techniques and specification required for welding. Section 3 describes our data collection procedure while section 4 focuses on the analyses and observation of the gathered data. Our design recommendation and comments are presented in section 5. Finally, the paper ends with conclusions and future work.

II. WELDING ON THE SHIPYARD

Welding is the process of joining two materials, usually metal or plastic by melting the surfaces and adding filler between the joints. A heat source is used to heat the edges of the joint allowing their fusion with the molten fill metal provided by an electrode, a wire or a rod. The filler cools and becomes a strong joint. [5].

Some forms of welding use gas, while others use an electric arc. The newest forms involve use of laser. The welding type

¹ For privacy issue the name of the shipyard cannot be mentioned

chosen depends on the form and thickness of the material, customer specifications, production rate and operational constraints [6], i.e. government regulations

The welding processes used on the shipyard are electric arc welding processes - that means high temperature heat of an electric arc joins the metal by fusing the parent metal to a joint using a consumable electrode. There are different forms of arc welding. Those currently used on the shipyard are the following [6]:

- **Shielded metal arc welding (SMAW)** – is a manual or semi-automated process using a consumable electrode with a dry flux coating held in a holder and fed to the work-piece by the welder. Manual SMAW may be used for down hand (flat), horizontal, vertical and overhead welding. SMAW is often referred to as “stick welding” and “arc welding”.
- **Submerged arc welding (SAW)** – is a flux-shielded electric arc welding process where a blanket of granulated flux is deposited on the work-piece, followed by a consumable bare metal wire electrode. The process is in general fully automated: the welding equipment is mounted on a moving carriage or self-propelled platform on top of the work-piece. The advantage of this process is that it produces high quality welds since the flux protects it from contaminants.
- **Gas metal arc welding (GMAW)** – is a welding process where an electric arc forms between a consumable wire electrode and the metal work pieces causing them to melt and join. Along with the electrode an externally supplied shielding gas feeds the welding gun. The gas protects the process from air contamination. This process enables continuously welding without the interruption of changing electrodes. It is often used in the automotive industry. GMAW, is also commonly referred to as *metal inert gas* (MIG) welding.
- **Gas tungsten arc welding (GTAW)** – is a type of gas-shielded welding process where the arc is generated between the work-piece and a tungsten electrode, which is not consumed. An inert gas, usually argon or helium, provides the shielding and provides for a clean, low-fume process. The process is also referred as TIG welding or Heliarc, because helium was initially used as the shielding gas.
- **Flux core arc welding (FCAW)** - similar to GMAW this process uses a wire that is fed continuously to the arc. The main difference is that the FCAW electrode is a tubular electrode wire with a flux core center that helps with localized shielding in the welding environment.

All these types of welding are used on the shipyard for ship construction and repair, as well as for rig building or other types of metallic structures.

Both equipment and parameter setting are important issues to consider when welding [6]. Regarding equipment, the following components are, particularly relevant:

a) the source power to supply a constant current/voltage independent of the speed of the wire feeder or distance of the welding gun

b) the electrode feeder which pulls the wire from a reel and puts it on the weld through a conduit in the welding torch; here the welders have to take care that there is enough electrode before starting the process as well as to avoid any obstructions that cause the electrode to not be provided

c) the welding torch or gun which includes a contact to transmit current to the electrode or a tube to supply the gas required to protect the weld against contaminations

d) the jigs which can hold parts in place during the welding process; in the case of a traditional shipyard it is common that others welders do this work.

Lastly, during the welding process there are several parameters that need to be taken into account (e.g. voltage, current, electrode length, gas, etc.), but the most important ones are:

a) the temperature applied to the weld; a low temperature would make impossible to weld the electrode and the metal, while a high temperature can destroy both the electrode and the metal as well as producing irregular welding. In order to control this, the welder commonly uses two indicator sticks one for low temperature and another for high temperature. It is required for the welder to continuously check the temperature and depending on the result to wait until the desired temperature is reached

b) the welding speed since it affects the heat transmitted to the base material. The speed affects the weld penetration because it relates with the time the arc acts on the material. Therefore, an excessive speed decreases penetration because the heat is not high enough in the welding zone.

III. DATA COLLECTION

Our data collection happened over a visit at the shipyard. It consisted of several interviews, photos, videos, notes and user observations. Four members of our research team were involved in the preparation and gathering of the data.

A. Interview preparation

To ensure an efficient data collection we prepared in advance a semi-structured interview. All the four members participated in developing questions that can be used during interviews. This technique is particularly helpful when trying to determine the optimal interview focus. Additionally, it enabled us to discover interesting research questions while taking into account the opinions of all those involved in the creative development process.

A total number of 36 notes were collected and pinned on a whiteboard to facilitate the overview (see figure 1). The notes were grouped in ten different topics. The topic grouping revealed that our development team members were mostly interested in questions addressing task characteristic: fifteen questions were dealing with task difficulty, easiness, boredom, degree of danger and degree of enjoyment. Therefore, we chose the interview to focus on welding task characteristic, i.e. half of the interview questions relate to this topic.



Figure 1. Whiteboard with our interview questions grouped around a particular topic

Further, we compared the remaining topics and found additional relevant questions for our interview. These questions were targeting major steps needed in welding, parameter setting, coordination required while working in teams, suggestion to improve working conditions, types of errors encountered and feed-back used to correct errors (see table 1).

Topic	Questions
Task characteristics (quantity, difficulty, easiness, boredom, degree of danger degree of enjoyment)	1. How many hours do you usually work? 2. How many welding jobs on average do you accomplish per day? 3. What is the most difficult /easiest part of the welding process? 4. Is there a welding step that you rather like to avoid and why? Is it dangerous or boring? 5. Can you describe a typical day at work? 6. What makes a good/bad day at work? 7. If you were a teacher and I was your student how would you teach me to weld? Which are the most important things I have to know about my new job?
Major steps needed in welding	8. Which tasks/steps are most commonly encountered in a welding session?
Parameter setting	9. Which parameters/tasks do you need to think of before you start welding? 10. How frequently do you need to set up these parameters?
Coordination	11. If you work together with someone else: how much communication to coordinate tasks do you need?
Improving suggestions	12. What can be done to improve your working conditions?
Types of errors	13. What can go wrong while welding? Types of errors and what makes a good quality welding on your opinion?
Feedback	14. To get a quality welding what do you have to pay attention to? Do you use sound or visual feed-back?

Table 1: Interview questions grouped around a topic

After filtering out repetitive questions and compressing statements to a single version the interview shrunk to a total of 14 questions. Also, we included demographic questions concerning age, country of origin, mother tongue, level of expertise, years of working in welding industry and, in particular, at the shipyard.

B. Pictures, Videos and Notes

Since a field study requires different tasks to be performed we decided to divide them equally between the team members:

each member was instructed to focus on specific task, such as video recording, taking pictures or writing down notes.

One and a half hour of video material was recorded. The videos focus on the shipyard surroundings, workers performing welding and detailed explanations of the welding tasks. A total of 262 photos were shot complementing the video recordings. The pictures depict the exterior of the shipyard (wide shot), welders along supervisors in the shipyard environment (mid-shot) and performing welding using the welding tools (close-up shot).

Observations were noted down during the visit, questions were clarified on the spot and first impressions were noted down right after the visit.

The five interviews with welders and supervisors were recorded resulting in another 1.5 hour of audio material. The interviews were afterwards manually transcribed to facilitate the analysis.

IV. DATA ANALYSIS

A. Observations

The shipyard we visited is spread over a total land area of 68 hectares and operates four graving docks. Within the shipyard area there are several large size halls where welding jobs are taking place. The metal plates, pipes and other metal materials to be used for welding are deposited outside the hall or on the hall's sides. To transport the materials inside or outside the hall, load rail flat wagons and cranes are used. The floor is covered with concrete and transversal flat metal bars (see figure 2).



Figure 2. Transversal flat metal bars covering the floor

The environment is relatively dusty, hot and loud due to ongoing working processes. However, the open endings ensure moderate ventilation. The hall receives natural light from outside. On the top, several neon lights provide additional light during the day and at night.

Most of the welding jobs we saw were done manually. Welders in groups of three up to four people are working individually. Each group is accompanied by a senior supervisor who assigns the daily welding jobs and ensures that the welding is performed in good conditions. After welding the welders clean the surface with brooms or metal brushes and remove additional loose metal parts with a special hammer (see figure 3a).

Some of the few automatic welding processes used on the shipyard were FCAW welding processes for T-joints, i.e. perpendicular connection between two metal plates. This

process of continuously welding was performed using an automatic machine that operates welding on horizontal, linear paths (see figure 3 c).

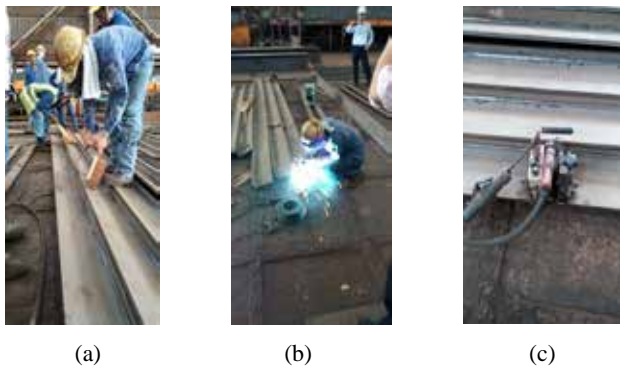


Figure 3. FCAW welding: welders cleaning (a); welder starting to weld (b); automatic welding machine (c)

Some of the few automatic welding processes used on the shipyard were FCAW welding processes for T-joints, i.e. perpendicular connection between two metal plates. This process of continuously welding was performed using an automatic machine that operates welding on horizontal, linear paths (see figure 3 c). However, the process is only partially automatic: human welders still need to start the welding, as shown in figure 3b, and join the plates on several points along the welding path to hold the plates together. This process ensures the regularity of the welding paths, i.e. a perfectly straight line for welding and enables the machine to do the rest. The welding of these holding points can be done only manually and requires coordination between the welders. For a good quality weld three welding passes are required.

In average, the automatic welding machine is up to three times faster as compared with the human welder. However, the machine can be used only for horizontal welding and only when the welding path is straight. If the path deviates from a straight line only manual welding can be done. Also, for edges, minor repairs or more critical places manual welding is used.

Another automatic welding process used on the shipyard is SAW welding. Here two long metal surfaces are weld together in a butt joint (see figure 4) using an automatic machine with granular fluxes.



Figure 4. Metal surfaces welded with SAW automatic welding

However, before starting the SAW welding the metal surfaces need to be first cut using a special cutting machine and then to be transported from the cutting place to the welding location. These operations, i.e. cutting and transport are currently performed by a human operator.

In contrast to welding of horizontal surfaces and inline plates, where automatic processes can be used, the welding of pipes for jack-up rig is done only manually. The complicated structure of the rig and the circular form of the pipes makes difficult to automatize the welding process given the current technological context of the shipyard.

The place is narrow and the pipe form requires the usage of a welding arm with 7 degrees of freedom to complete a full pass. Currently, the most advanced robots used in welding have only 6 degrees of freedom. Another impediment is the welding type used: at the moment, SMAW welding is deployed in the rig construction; this type of welding requires the replacement of the electrode after each use, i.e. it is not a continuous welding process.

To access the rig structure welders use scaffolding or elevators. It takes about 2 weeks to align a complete rig structure. Firstly, the pipes need to be profile cut using a special cutting machine. Next, the pipes are brought by crane and placed on the joint location. Here, special care is needed to ensure that the pipes are placed according to the measurements specified on the construction plan. Once the alignment is proof checked, the welders attach a metal holder that keeps the pipes together and start filling the gap between them (see figure 5).



Figure 5. Engineer explaining how two pipes have to be fixed on the rig structure

The pipes are assembled on the ground in the hall area. After that, the structure is brought outside and put up in standing position; then, the rig is further extended and when ready, it is brought off to the sea.

Within the hall area the rig structure is surrounded by a plastic wrap (see figure 6).



Figure 6. Rig structure wrapped in plastic

This helps protecting the environment from the toxic vapors produced by the disintegration of the electrode flux coating which also serves as a shielding gas.

In general, the welding process does not seem to be difficult to perform. However, it requires quite a lot of physical activity: welders are often standing, bending over, stretching their arms to reach a remote point while squatting under a pipe structure, getting on their knees (see figure 8) or climbing on

jack-up rig. Welders told us that after a welding round they always need to rest for some time.



Figure 7. Welders working under the pipe structures

B. Interviews

We interviewed six persons in total: five welders and an engineer in charge of the welding training. The welders were chosen from two representative ethnical groups (Bangladesh, India) and having different type of expertise: beginners, intermediary level and advanced.

The vast majority of welders on the shipyard were foreigners. Those who were interviewed were from India (1) and Bangladesh (4). They were speaking Telugu and Bengali as mother tongue and were aged between 19 to 45.

Normally, welders are recruited in their native country. Some have welding experience while others are complete beginners. On the shipyard they receive training courses and become certified welders. Since their level of English is relatively low, senior fellows and supervisors often help by translating. During our interview we experienced communication problems with two Bengali welders but luckily, we received help from a senior welder with better English knowledge.

The interviewed welders had different levels of expertise: one was a beginner with one year and a half of welding experience, while others were more advanced welders: three of them had six and respectively seven years welding experience, while the welder supervisor had worked in welding for more than 15 years. All, except one have gathered their working experience on the shipyard.

Welders usually work between 8 and 11 hours daily. When welding manually, the productivity of an intermediary/advance welder is around 50 meters per day compared with 40-45 meters for a beginner. If using an automatic machine 100 meters of welding can be achieved in one day.

The easiest welding task is inline welding. Here only some holding points are required to be welded manually and the rest is done automatically by the machine. In contrast, the most difficult welding task is upper welding on the jack-up. This is considered not only the most difficult but also the most dangerous welding task.

A usual day on the shipyard involves three main activities: the welding preparation, the welding itself and the communication with others co-workers. The welding preparation involves first, the careful cleaning of the surface to ensure that no other particles are left and, second, the surface preheating. The temperature needs to be checked every 30-40 minutes: if the temperature is too low, the metal needs to be further heated; if the temperature is too high, the metal needs to

be cooled down and welders have to wait about ten minutes for the cooling, time in which they can rest and drink water. These two preparative steps are very important; if ignored, they can cause gaps between the joints which will further contribute to weld disintegration.

For the welding process itself, it is important to check the welding proceeding specification to ensure a correct parameter setting, i.e. what current, voltage, speed etc. are required. Usually, manufactures recommend some parameters for certain types of electrodes. Some of the newer welding machines have displays where the ampere and voltage come with a portable reader. The speed is generally pre-programmed. Depending on the welding material, welding position, type and direction – downhill or uphill – the parameter settings can vary. However, before starting to weld, it is important to perform a test on a metal piece to check the parameter adjustments. Also, once the parameters are set, it is important to maintain the current and the voltage constant during welding. Additionally, welders need to be aware of the welding path and take into account any small deviation. As far as concerning the pipes, welders need to ensure that these are placed on the right spot and that the fitting accuracy is 100%.

To determine whether they are doing the “right thing” welders often rely on supervisor’s advices and on their own “feelings”. As one welder said: “*You can feel when you do it right*”.

Welders are talking with each other when working together but the actual work coordination between them is often mediated by a supervisor. Also, when “in doubt” welders rely mostly on the supervisor’s directions, or follow senior welders. Welding in pairs, i.e. at the same time, occurs especially when welding the rig’s legs.

The welding processes can be hindered if the metal plate is not heated enough, the surface is wet or there is too much wind in the environment. Black smoke, increased heat from the surface, as well as certain sounds while welding are indicators that something is going wrong with the weld.

When asked what are the things that bothers them most, welders told us about the heat which sometimes is very difficult to handle, the smoke and their difficulties to breath properly. The environment is also very loud, which adds additional stress on the welders. Working in groups underneath the rig structure in tight, narrow places also increases the perception of heat. One welder told us about a bad experience he had: “*sparks were coming out .. my eyes [were] so painful .. then, you don’t like to work, eyes can get very tired. Sometime at night I cannot close my eyes*”. Such hazards can happen if the eye mask does not close well and enables the light to come in.

Another welder was confessing: “*Physically, it is not difficult but body gets hot and we need to take some rest, we cannot work continuously*”, while a third welder described how his working clothes were burned by sparks that came out while welding. As confirmed by the senior engineer, the most common hazards on the shipyard are electrical, i.e. voltage related.

As a beginner, a welder should pay attention to safety features, welding requirements, follow senior welders, learn 'by doing' and prepare the welding very carefully. Also, all welders highlighted the importance of following safety proceedings.

V. DESIGN RECOMMENDATIONS

The information gathered from observations and interviews helped us to come up with a set of design recommendation as listed below.

1. Mobility and safe movement. For moving on the floor the robotic platform must take into account the fact that the area is not flat, i.e. metal flat bars are placed on the floor. This might hinder the robot movements. A possible solution could be to mount the robot on a special rail track platform.

Another issue concerns the robot's movement around the shipyard. This issue can be handled by placing sensors and cameras on the robot for visual feed-back on directions and safety. However, this problem is secondary, since in our current scenario the robot is accompanied by a human operator who ensures the robot reaches safely the welding location.

2. Accessibility to the weld site. To access the vertical rig structure the robot can make use of the existent scaffolds or the crane. The robot can be placed on a mobile platform on the scaffold having additional bracings attached to impede the scaffold to shake while the robot is moving. The robot can be also moved and placed at any weld location on the rig using a crane. Another possible solution could be a stand-alone platform that would have the ability to move around and raise the robot to the required height.

3. Robustness. The robot platform needs to be robust to outdoors and harsh industrial operating conditions such as those we found on the shipyard: dust, high temperature, and certain air quality conditions generated during the welding operation.

4. Welding preparations and adjustments. Once manually positioned near the welding location the robot should be able to scan the area for any obstructions and calculate the weld paths required for the joint. Here, the lighting condition should be taken into account: during the evening time there might not be sufficient light available. A possible solution could be a portable, flexible lamp attached to the robotic platform.

The robot is also required to adjust parameters and prepare for the welding. One important element welders mentioned during the interview was their capacity of "feeling" whether the parameters were correctly adjusted. Such capability is very difficult to implement in the robot and currently we rely only on welding specification proceedings to pre-program the robot.

5. Welding process. For the welding operation the robot must be able of carrying a welding system at the tool tip. There are several welding systems, such as stick, MIG or TIG suitable for this application. The most suitable welding process is the MIG welding because it enables continuously welding without the interruption of changing electrodes.

As highlighted before the pipes have a circular form, which requires an arm with 7 degrees of freedom for a full weld pass. Since currently there are no robots with such capabilities, a solution could be to change the robot position by moving it around the pipe to the other side. Another solution could be to use two robots placed at opposite sides of the pipe.

6. User interface. Since the welding robot will be probably used in a tele-operation scenario to perform welding on a jack-up rig the user interface could combine different input/output modalities, such as visual, text and speech. It is important to take into account the welders profile, whose level of English is relatively low and highly accented, as well as the loud environment in the shipyard. A possible solution could be to implement a speaker dependent system, i.e. a system that is trained with the speech of a certain user. The vocabulary could also be limited to a set of keywords, which would enhance recognition performance. Parameter settings and adjustment could be represented using images.

VI. CONCLUSIONS

Welding is not a difficult process, it can be learned easily but mastering it requires time. Mechanizing certain processes for the shipyard is a challenging task but the effort to develop a robotic platform is worth trying. The deployment of a robot would increase the productivity and protect human welders from being exposed to hazards of any kinds, such as electrical, burns eye damage and working in dangerous locations.

Our next step is to define several use case scenarios for the robot and to test our scenarios in the shipyard environment. Several set-up parameters will be taken into account and tested accordingly. Additionally, a reliable solution must be found for getting feed-back on parameters adjustments since the human capability of "feeling" is impossible to reproduce in a robot. Finally, we are planning to develop an interactive interface that combines different input/output modalities and to test it with real human welders.

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